Design of an Axially Displaced Ellipsoid Reflector Antenna for a 4.6m Diameter Ship-Borne Transportable Terminal at S-Band

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Abstract—**This paper presents a detailed study for realization of an optimized configuration of a 4.6 m diameter reflector antenna for ship-borne transportable terminal using axially displaced ellipsoid (ADE) configuration. Maximum gain achievable from the aperture coupled with system level parameters like G/T, accommodation of a feed capable of simultaneous uplink and downlink involving monopulse tracking and ease of assembly on a moving and constrained workplace like ship or a truck is also major driving parameter in the design. These parameters are explicitly analyzed and discussed in this paper.**

Keywords- axially displaced ellipsoid, ADE, reflector antenna, ship-borne antenna

I. Introduction

Transportable terminals are generally deployed to extend or fill the gaps in the critical coverage requirement in telemetry, tracking and command (TT&C) network support for satellite launch vehicle or atmospheric re-entry missions. A 4.6 m reflector antenna is planned for such a ship-borne terminal. The bands of operation are 2025–2120 MHz for uplink and 2200–2300 MHz for downlink.

A continuously tracking ship-borne antenna design is very complex due to stringent mechanical constraints. It has to be light in weight, small in volume, easy to assemble, align and also dismantle with very scarce available recourses and at the same time withstanding harsh sea environment. The mechanical design limits the depth of main reflector to be less than 0.7 m and the height of feed structure containing the feed, sub-reflector (if applicable) and struts to be less than 1.8 m from the vertex of the main reflector. So to ease the assembly and alignment a mono-pod configuration is primarily chosen for the feed and sub-reflector (if applicable) assembly.

Four different reflector configurations are considered as possible options for this application. They are (i) Prime-focus, (ii) Cassegrain, (iii) Gregorian and (iv) Axially Displaced Ellipsoid (ADE). To have a monopod configuration, Prime-focus, Cassegrain or Gregorian geometries are not that suitable. However, axially displaced ellipsoid (ADE) configuration is very popular for realizing high efficiency from a small aperture reflector antenna [1]-[2].

The directivity values for all the four configurations as obtained from [3] are shown in Table-I. It can be noted that the ADE provides maximum directivity for the reflector with diameter ≈ $33\lambda_0$. Moreover, the feed taper requirement for different configurations shows that ADE needs a feed with the lowest gain i.e. the feed aperture will be the smallest. In this simulation, the blockage due to sub-reflector or the feed are not considered. Hence the realizable directivity will still be lower except in the case of ADE. This has been explained in the following sections. The primary design requirement is to maximize G/T at the receive frequency band, the specification being 15 dB/K at 10° elevation. Several design parameters are to be properly selected to meet the electrical performance and at the same time it should meet the mechanical requirements.

TABLE-I: COMPARISON OF THE FOUR CONFIGURATIONS; $D_M = 4.6$ M; FREQ 2.15 GHZ

Configuration	Directivity (dBi)	G/T (dB/K)
Prime-focus	38.2	14.9
Cassegrain	38.6	15.9
Gregorian	38.5	15.8
ADE	38.9	16.2

II. Optimization of ADE Parameters

In ADE, the main reflector is generated by rotating the displaced section of a parabola about the symmetry axis of the antenna. Thus it will have a ring caustic instead of a single focal point. A tilted axis ellipse which is offset so that one of its foci is on the antenna symmetry axis (system focus F_s) and the other coinciding with the ring caustic of the parabola, is rotated about this symmetry axis to form the sub-reflector, thus the name ADE [1]. The main advantage of this geometry is that the sub-reflector scatters majority of the feed radiation away from the vertex of the main reflector thus the effect of blockage due to sub-reflector will be less and thus it can provide higher efficiency even for electrically small reflector.

The design parameters for ADE are main reflector diameter (D_m), blockage diameter (D_b), sub-reflector diameter (D_s), half cone angle subtended by sub-reflector at system focus (θ_E), and the distance between main and sub-reflector ($l_o/2$). The parameters can be found in [2]. In the present design, D_m = 4.6 m, D_b and D_s are kept equal and θ_E is selected as 45°. To meet the mechanical requirements, l_o is chosen as $0.75 \times D_m$. Hence the only optimization parameters are D_s (or D_b) and the feed taper at ±45°. The optimization is done by varying D_s from 0.09 to 0.16 at an interval of 0.01 and feed taper at ±45° is varied from -10 dB to -20 dB at an interval of 2.5 dB as shown in Table-III to choose the geometry which gives maximum efficiency. The other parameters like the focal length (F_p) of the parabola and

TABLE-II: PARAMETERS OF DIFFERENT TYPES OF THE ADE ANTENNA

D_s/D_m	F_p(mm)	Depth of Main Reflector (mm)	2c (mm)
0.09	1575	700	236
0.10	1552	694	253
0.11	1535	683	278
0.12	1518	675	303
0.13	1501	667	323
0.14	1483	659	354
0.15	1466	652	379
0.16	1449	644	405

TABLE-III: SIMULATED RESULTS [3] OF THE ANTENNAS AS IN TABLE-II

D_s/D_m	Directivity (dBi) at 2.15 GHz				
	-10 dB Taper	-12.5 dB Taper	-15 dB Taper	-17.5 dB Taper	-20 dB Taper
0.09	38.21	38.36	38.42	38.42	38.38
0.10	38.33	38.47	38.51	38.48	38.46
0.11	38.42	38.53	38.58	38.56	38.51
0.12	38.57	38.68	38.72	38.72	38.71
0.13	38.65	38.75	38.79	38.71	38.67
0.14	38.85	38.89	38.89	38.83	38.81
0.15	38.81	38.91	38.91	38.86	38.81
0.16	38.67	38.78	38.83	38.82	38.79

eccentricity (*e*), distance between foci (2*c*), tilt angle (β) of the ellipse are calculated using the equations in [1].

For varying feed taper and D_s, the value of *e* and β are kept unchanged at 0.5618 and 65.4° respectively. The other derived parameters are provided in Table-II. The profiles for main reflector and sub-reflector for the above mentioned parameters are generated in MATLAB. A study is done using two different softwares that use two different techniques to choose an optimum value of D_s and the feed taper accurately.

III. SIMULATED RESULTS

Initially, analysis has been carried out for different values of D_s using [3] that uses asymptotic solution using Physical Optics/Physical theory of Diffraction (PO/PTD). The results of the analysis, provided in Table-III, show that maximum efficiency is achieved for a D_s/D_m = 0.15 and for an edge illumination taper of -15 dB at ±45°.

It is convenient to design reflectors using [3]. But for small reflector as in the present case, the results may not be very accurate. So to validate the results, analysis has been carried out using a method of moments (MoM) based analysis tool [4]. Both the reflectors for the above mentioned configurations are modeled along with the feed which provides the illumination taper of -15 dB at ± 45°. The 3D model of an ADE is shown in Fig. 1. The directivities calculated at 2.15 GHz in [4] are compared with the values from [3] for varying values of D_s/D_m in Fig. 2. The results show that, there is significant difference in D_s/D_m values for maximum directivity. From [3] peak directivity is achieved for a larger D_s/D_m (0.15) whereas from [4] it is at smaller D_s/D_m (0.1). The increase in the size of the sub-reflector results in higher blockage which is accurately accounted in MoM based simulations. However, considering the area required for accommodating the feed a sub-reflector with D_s/D_m = 0.12 is selected where the directivity is about 0.2 dB less than the

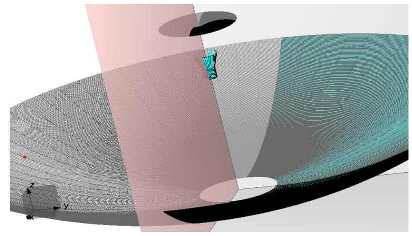

Fig. 1. Three dimensional schematic of the ADE configuration with the feed as modeled in [4]

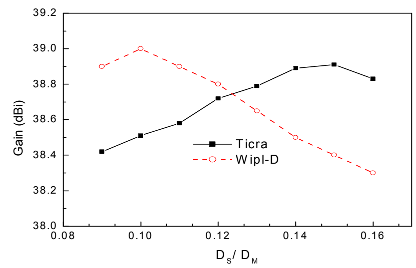

Fig. 2. Comparison of gain for varying D_s/D_m values from [3] and [4]

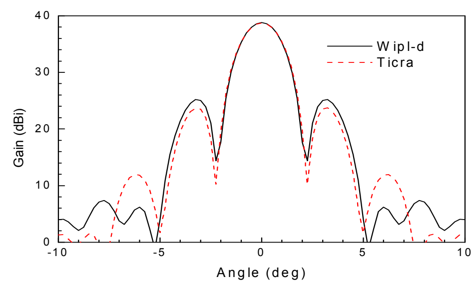

Fig. 3. Simulated radiation patterns at 2.15 GHz obtained from [3] and [4] for D_s/D_m = 0.12

peak value. Fig. 3 shows the simulated secondary radiation patterns at 2.15 GHz obtained from [3] and [4]. Very good formation of nulls and side lobe level of -14 dB indicates very good illumination of the aperture. The result from [4] shows slightly higher side lobe. The peak gain of the antenna is 38.75 dBi which is about 70% aperture efficiency. The antenna is under fabrication and the measured results will be reported.

IV. CONCLUSION

An efficient dual reflector antenna using ADE configuration is designed and simulated for a very small aperture considering an optimum value of D_s/D_m and the feed taper. MoM based analysis is used to validate PO based results for electrically small antenna. The design also considers the stringent mechanical constraints of light weight and compactness.

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[4] WIPL-D Pro, version 10.0.